

CLINICAL INVESTIGATION

Prolonged Tele-Critical Care Utilization Is Associated With Improved ICU Outcomes: Evidence From Veterans Affairs Hospitals

OBJECTIVES: To determine the impact of critical care telemedicine (tele-critical care [TCC]) implementation duration on clinical outcomes: ICU mortality, ICU length of stay (LOS), and mechanical ventilation utilization.

DESIGN: Retrospective cohort study.

SETTING: Thirty-five U.S. Department of Veterans Affairs (VA) hospitals (444 ICU beds) that used TCC between 2012 and 2020.

PATIENTS: One hundred ninety-three thousand three hundred sixty-seven patient stays meeting specific inclusion criteria from 2012 to 2020 were included in the study.

INTERVENTIONS: Critical care telemedicine (TCC) implementation.

MEASUREMENTS AND MAIN RESULTS: The standardized ICU mortality rate was calculated by comparing patient outcomes to expected outcomes, utilizing critical care prediction models. ICU LOS was standardized for illness severity and case mix. The rate of invasive mechanical ventilation was analyzed, comparing ventilator days against predicted values. Longer TCC utilization was linked with a trend toward lower standardized ICU mortality rates, with statistically significant reductions after a 5-year period. ICU LOS also showed a significant decrease with prolonged TCC deployment. While the rate of invasive mechanical ventilation declined over time, it was not significantly related to the TCC deployment duration.

CONCLUSIONS: Extended TCC implementation improves ICU mortality rates and reduces ICU LOS. Longer TCC deployment has clear benefits on patient outcomes in the VA healthcare system. Further research should explore long-term effects and factors influencing TCC adoption.

KEYWORDS: clinical outcomes; intensive care unit; length of stay; mortality; predictive models; tele-critical care

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The widespread adoption of critical care telemedicine (tele-critical care [TCC]) enables monitoring and management of ICU patients by remotely located critical care providers expanding the multidisciplinary ICU team and providing critical care expertise when and where it is most needed (1). Within the United States, approximately 15% of all ICU beds use TCC (2). Through multiple interfaces with bedside monitors and other equipment, electronic medical records, and hospital laboratories, TCC enables comprehensive remote monitoring and management of multiple patients by a team of tele-intensivists and nurses, aiding in early detection and intervention. Furthermore, TCC facilitates the collection and analysis of data for quality improvement initiatives and research. It also presents an opportunity to

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KEY POINTS

Question: How does the duration of critical care telemedicine (tele-critical care [TCC]) implementation affect clinical outcomes measured by ICU mortality, ICU length of stay (LOS), and the use of mechanical ventilation in U.S. Department of Veterans Affairs hospitals?

Findings: Longer TCC utilization demonstrates a trend toward lower standardized ICU mortality rates, with significant reductions observed after 5 years of implementation. Additionally, prolonged TCC deployment significantly decreases ICU LOS. While the use of invasive mechanical ventilation declined over the study period, this reduction was not significantly associated with the duration of TCC deployment.

Meanings: Extended TCC implementation enhances clinical outcomes by reducing ICU mortality rates and ICU LOS. These findings suggest that sustained use of TCC may provide substantial benefits in patient care. Further research is needed to explore the mechanisms behind these improvements and factors influencing the successful adoption of TCC in healthcare settings.

implement standardized care protocols and guidelines across different facilities within a health system and, potentially, in the future, artificial intelligence-based adjuncts to critical care management (3).

TCC is generally associated with improved critical care outcomes (4), although the results can be heterogeneous. Three meta-analyses of the effect of TCC on ICU and hospital mortality demonstrated improvement in ICU mortality but mixed effects on hospital mortality (5–7). These analyses showed a decrease in ICU length of stay (LOS) but mixed findings on hospital LOS. Although another study showed overall mortality improvement with TCC, the effect varied widely with 12% of hospitals showing improvement, 81% no effect, and 6% increased mortality (8). When used to manage individuals who received mechanical ventilatory support for nonpostoperative acute respiratory failure, one study showed TCC did not affect mortality, tracheostomy or reintubation rate, or duration of ventilatory support (9). Another study demonstrated that TCC-directed daily ventilator rounds reduced

ventilator duration ratio (actual days of ventilatory support/Acute Physiology and Chronic Health Evaluation [APACHE] IV predicted days of ventilation), improved adherence to lung protective ventilation, and decreased ICU mortality (10). Spies et al (11) showed that TCC facilitated early weaning from mechanical ventilation.

Despite numerous studies, the causes of the varied effects of TCC remain unclear. The effectiveness of the TCC team may depend on its interactions with bedside staff (12). TCCs that operate with decision making authority rather than strictly consultative functionality are associated with better outcomes (13). Fusaro et al (7) noted that studies where the observed-to-predicted ICU mortality ratios were greater than 1 before TCC implementation were associated with a reduction in ICU mortality after TCC implementation, whereas no significant ICU mortality reduction was noted when the observed-to-predicted ICU mortality ratio was less than 1 before TCC implementation. Other factors that might influence TCC clinical efficacy include operational practices (14), frequency of interactions between the TCC and the bedside (15) and patient acuity (16–19). This study explores the connections between implementation duration and clinical outcomes, addressing a gap as most research has focused on short-term TCC usage. To assess the impact of prolonged implementation, we examine the long-term effects on mortality, LOS, and mechanical ventilation within the Veterans Affairs (VA) National TeleCritical Care Program.

MATERIALS AND METHODS

Study Population

This analysis focused exclusively on the 35 VA hospitals (444 ICU Beds) that implemented TCC utilizing eCareManager (Philips Medical Systems Nederland B.V., Eindhoven, The Netherlands) between 2012 and 2019. The VA TeleCritical Care Program was initiated in 2011 with six facilities and subsequently grew to 12 facilities in 2012, and 35 facilities in 2019. During this period, two facilities decommissioned their ICUs and one facility stopped TCC participation. Data on patient demographics, diagnosis, physiologic and biochemical markers, treatment, and discharge status were collected in the eCareManager database. The study focused on patients admitted to the VA TeleCritical Care Program from 2012 to 2019 (inclusive). Patients admitted in 2011 were omitted due to smaller numbers and short

TCC implementation duration and patients admitted from 2020 onward were omitted due to the COVID pandemic. This study was undertaken as a quality review of TCC clinical efficacy using de-identified retrospective data of prior patients. This study was exempt from Institutional Review Board oversight since there were no patient interventions due to the study's retrospective design. To improve quality from the ICU perspective, each patient stay was treated as a separate admission with a new diagnosis unless the readmission happened within 6 hours due to unit transfer or surgical procedures. In that case, it was counted as part of the previous stay. The total number of patient stays included in the study was 193,367 admissions. Patient and facility demographics are summarized in **Table 1**. **Supplementary Table 1** (<https://links.lww.com/CCM/H783>) shows the counts for facilities, bed activation, and complexity level over the study period.

TABLE 1.
Patient Demographics and Facility Characteristics

Characteristics	Statistics
Number of patients	193,367
Discharge year	2012–2019
Gender	95.3% male, 4.6% female, 0.1% others
Age (yr)	63 ± 17.5
Patient discharge status	Alive = 93.7%, deceased = 6.3%
Unit length of stay (d)	2.83 ± 3.58
VA facilities	35
VA facility complexity level	
1a	5
1b	6
1c	4
2	16
3	3
ICU beds total (in 2019)	444
Critical care beds/ICU (range) (beds)	4–29
Total number of patients receiving invasive mechanical ventilation	20,437
Total number of days of invasive mechanical ventilation (d)	74,787

VA = U.S. Department of Veterans Affairs.

Modeling and Data Analysis

For this analysis, we employed the Philips Critical Care Outcome Prediction Models, which encompass an ICU predictive mortality model (20) and an ICU predictive LOS model (21, 22). Additionally, we used models designed to predict the duration (23) and probability (24) of ICU invasive ventilation. Invasive ventilation was defined as endotracheal or tracheal intubation with mechanical ventilation. These models were benchmarked against current standards (including APACHE models as well as measured outcomes) and demonstrated enhanced performance and improved capacity to manage missing and inaccurate data. These models also account for variations in patient severity and case mix, facilitating standardized comparisons across different hospitals and times. Information regarding the model inputs, outputs, training, and performance is detailed in earlier publications (20, 23, 24). **Supplementary Table 2** (<https://links.lww.com/CCM/H783>) outlines the data used for training, validation, and testing for each model, while **Supplementary Table 3** (<https://links.lww.com/CCM/H783>) lists the input features specific to each model. Although there are some similarities in features, each model has distinct differences. Variations in inclusion and exclusion criteria, along with other conditions, are described in the aforementioned publications. Consequently, while the same overall population was studied, the analysis for each model involved slightly different numbers of stays, tailored to each model's unique criteria.

Data acquired during the first 24 hours of patient stay were used to generate predictions for mortality, length of ICU stay, and utilization of invasive ventilation during the whole ICU stay (17–20). The ratio of actual values (A) over the predicted values (P) was then used to calculate “Standardized” values (A/P). Standardized population outcomes were calculated using the ratio of the sum of actual outcomes to the sum of predicted outcomes (A/P statistics) for patients across specific hospitals and time periods.

Inclusion Criteria and Data Split

The inclusion criteria for patient stays were: 1) a total ICU LOS exceeding 4 hours, 2) patient age over 16 years at the time of admission, and 3) availability of all model features for predictions (for model features, see

Supplementary Table 3 (<https://links.lww.com/CCM/H783>), as well as references [20, 21, 23, 24]].

Statistical Analysis

To elucidate the relationship between ICU deployment duration and standardized outcomes, we employed a linear regression model. Furthermore, an independent two-sample *t* test was conducted to assess the temporal impact of TCC deployment on standardized outcomes, comparing pre- and post-deployment means. Results are presented as mean ± SD, with statistical significance set at *p* value of less than 0.05. All analyses were performed using Python 3.7 (Python Software Foundation Beaverton, OR).

RESULTS

Mortality

We examined the relationship between the duration of TCC deployment and standardized ICU mortality rate. **Figure 1A** illustrates the annual count of unique patient admissions to TCC per year that met the inclusion criteria for the predictive mortality model. **Figure 1B** shows the standardized annual hospital mortality rate by year across hospitals.

Figure 1C shows the standardized mortality rate as a function of the number of years of TCC deployment. Our findings indicate a trend toward a negative correlation between the duration of TCC implementation and standardized mortality rates, with a correlation coefficient of -0.02 ($p = 0.06$; Fig. 1C). To determine if there might be a duration threshold for TCC’s effect on standardized mortality rate, we compared groups of hospitals with less than or equal to *x* and greater than *x* years of TCC affiliation with *x* ranging between 1 and 7 years of TCC affiliation (**Supplementary Fig. 1**, <https://links.lww.com/CCM/H783>). The actual/predicted standardized mortality rate remained unchanged (fold change = 0.87; $p = 0.10$) for TCC durations over 4 years compared with 4 years or less (**Fig. 2A**). However, for TCC durations over 5 years compared with 5 years or less, the actual/predicted standardized mortality rate decreased (fold change = 0.82; $p = 0.04$; **Fig. 2B**). Similar associations were observed for thresholds of 6 and 7 years of TCC deployment (**Supplementary Fig. 1**, <https://links.lww.com/CCM/H783>).

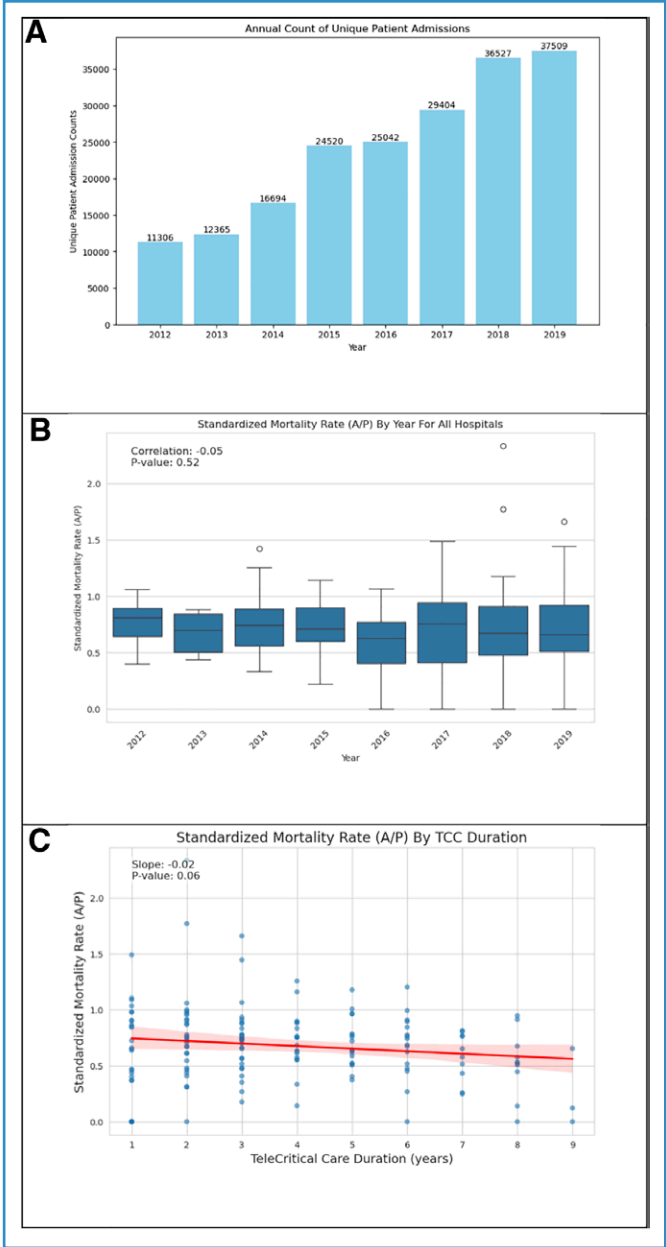


Figure 1. Standardized ICU mortality and tele-critical care (TCC) duration. **A**, Annual number of unique patient admissions used in analyzing mortality. **B**, Standardized ICU mortality rate (ratio of actual values over predicted values [A/P]) by year. **C**, Standardized ICU mortality ratio (A/P) as a function of duration of TCC deployment (yr).

Length of Stay

We examined the relationship between the duration of TCC deployment and ICU LOS. **Figure 3A** displays the number of ICU admissions per year (who satisfied the inclusion criteria for the model) considered for this analysis. **Figure 3B** illustrates the standardized ICU LOS (A/P) for each year. The annual mean standardized ICU LOS did not change over the study period

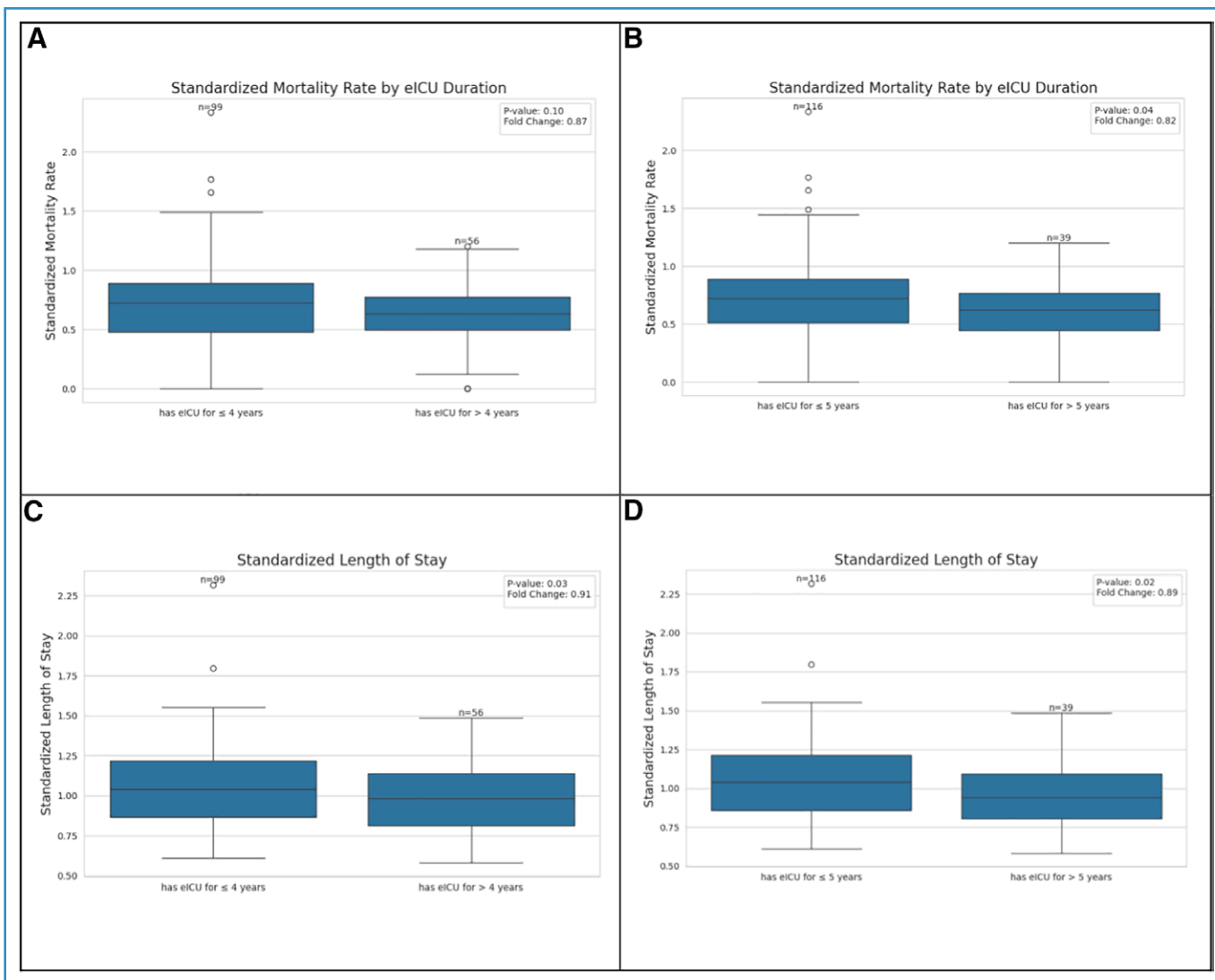


Figure 2. Tele-critical care (TCC) implementation duration and ICU outcomes: standardized ICU mortality and ICU length of stay. Standardized ICU mortality rate (ratio of actual values over predicted values [A/P]) (**A** and **B**), standardized length of stay ratio (A/P) (**C** and **D**), in groups of hospitals with TCC implementation durations less than or equal to 4 and greater than 4 yr and less than or equal to 5 and greater than 5 yr, respectively (see Supplementary Figs. 1 and 2, <https://links.lww.com/CCM/H783>, for a more comprehensive comparative analysis across utilization thresholds ranging from 1 to 7 yr). eICU = electronic ICU.

(Fig. 3B). However, the standardized ICU LOS demonstrated a significant negative correlation with the length of TCC deployment (correlation coefficient = -0.033 ; $p = 0.003$; **Fig. 3C**). The actual/predicted ICU LOS was reduced (fold change = 0.92 ; $p = 0.03$) for TCC duration greater than 4 years compared with less than or equal to 4 years (**Fig. 2C**). Additionally, the actual/predicted ICU LOS was decreased (fold change = 0.90 ; $p = 0.02$) for TCC duration greater than 5 years compared with less than or equal to 5 years (**Fig. 2D**) and similar associations were observed for thresholds of 6 and 7 years of TCC deployment (**Supplementary Fig. 2**, <https://links.lww.com/CCM/H783>).

Invasive Ventilation

Actual and predicted values were calculated per patient stay, focusing on the probability of invasive ventilation (23, 24).

In total, we analyzed 143,000 admissions for mechanical (invasive) ventilation who had no data fields missing for the calculation of the predictive values and who also satisfied the inclusion criteria defined previously (23, 24). During the timeframe under review, 17.5% of ICU patients in the VA received invasive ventilation. **Figure 4A** shows the annual number of admissions reviewed in the invasive ventilation analysis. The

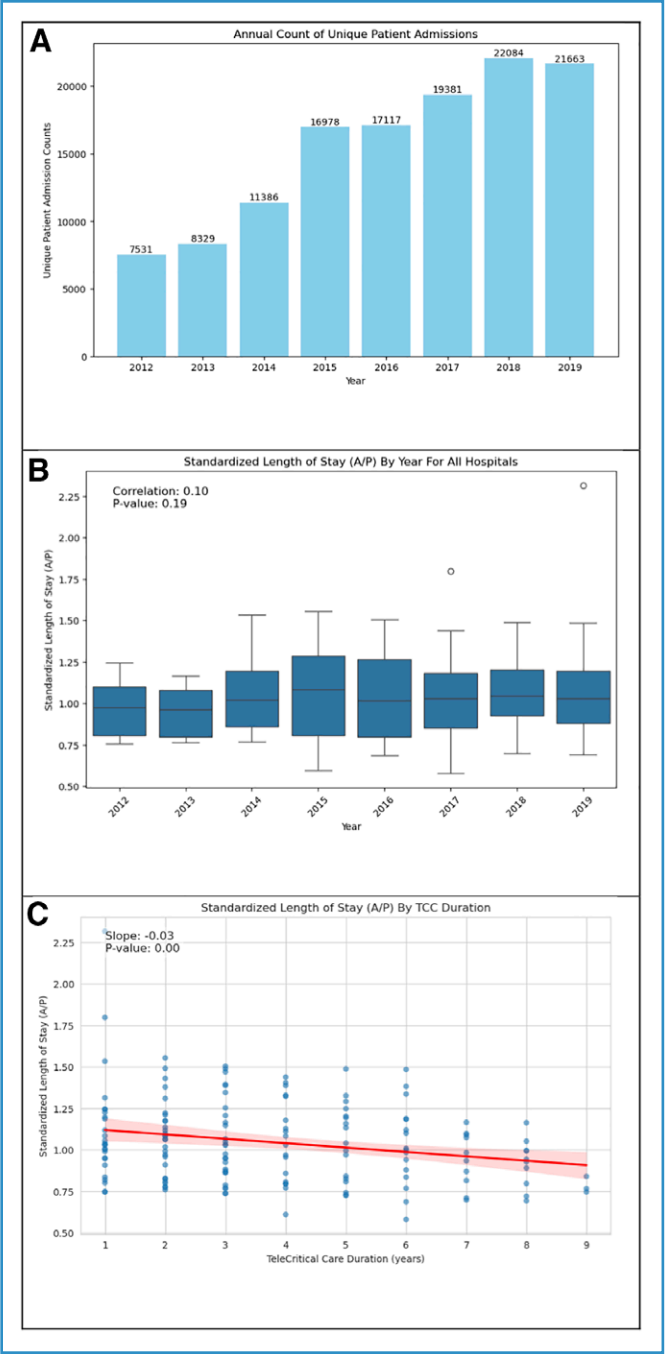


Figure 3. Standardized ICU length of stay and tele-critical care (TCC) duration. **A**, Annual number of unique patient admissions used in analyzing length of stay. **B**, Standardized length of stay ratio (ratio of actual values over predicted values [A/P]) by year. **C**, Standardized ICU length of stay (A/P) as a function of duration of TCC deployment (yr).

annual mean standardized invasive mechanical ventilation rate was less than 0.5 and decreased throughout the study period ($p = 0.01$) (**Fig. 4B**). The standardized invasive mechanical ventilation rate did not change as a function of the duration of TCC deployment (slope = 0.013; $p = 0.11$; **Fig. 4C**). Thus, although the

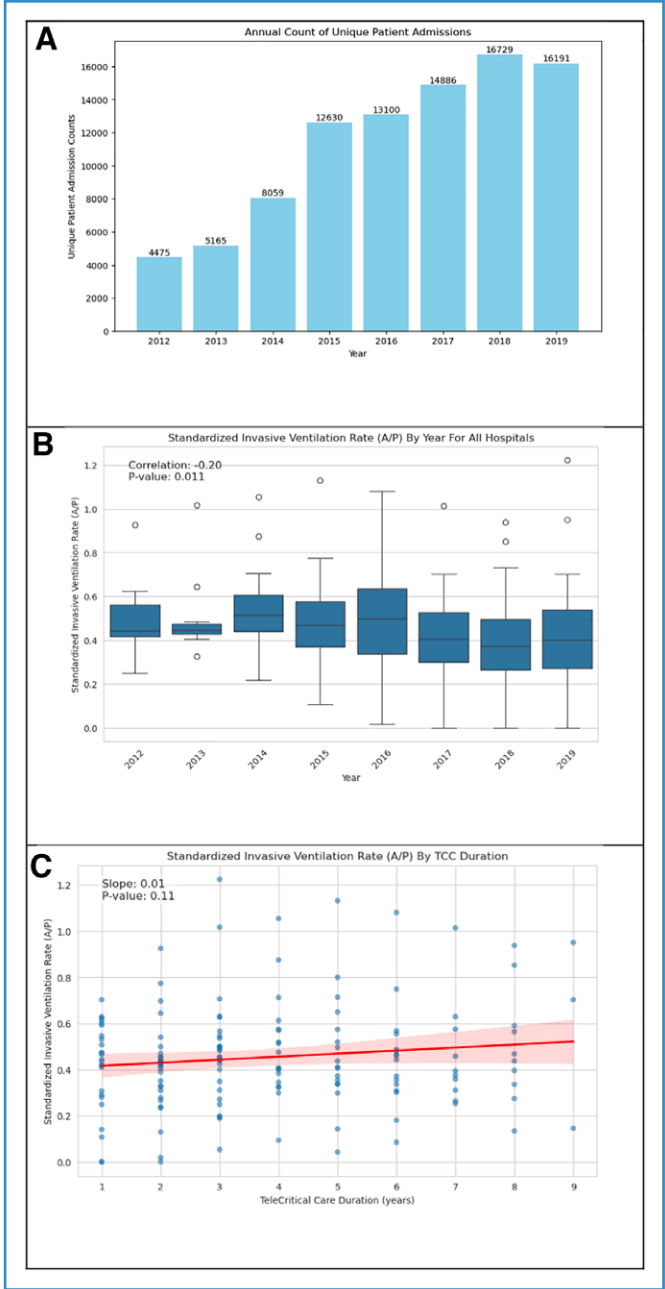


Figure 4. Standardized invasive ventilation deployment and tele-critical care (TCC) duration. **A**, Annual number of unique patient admissions used for analyzing the rate of invasive ventilation per year. **B**, Standardized invasive ventilation (ratio of actual values over predicted values [A/P]) by year. **C**, Standardized rate of invasive ventilation e (A/P) as a function of duration of TCC deployment (yr).

use of invasive ventilation over the period of TCC deployment declined ($p = 0.01$), this decrease was not significantly associated with the duration of TCC utilization. The actual/predicted invasive mechanical ventilation rate did not differ for TCC duration less than or equal to 4 years compared with greater than 4 years

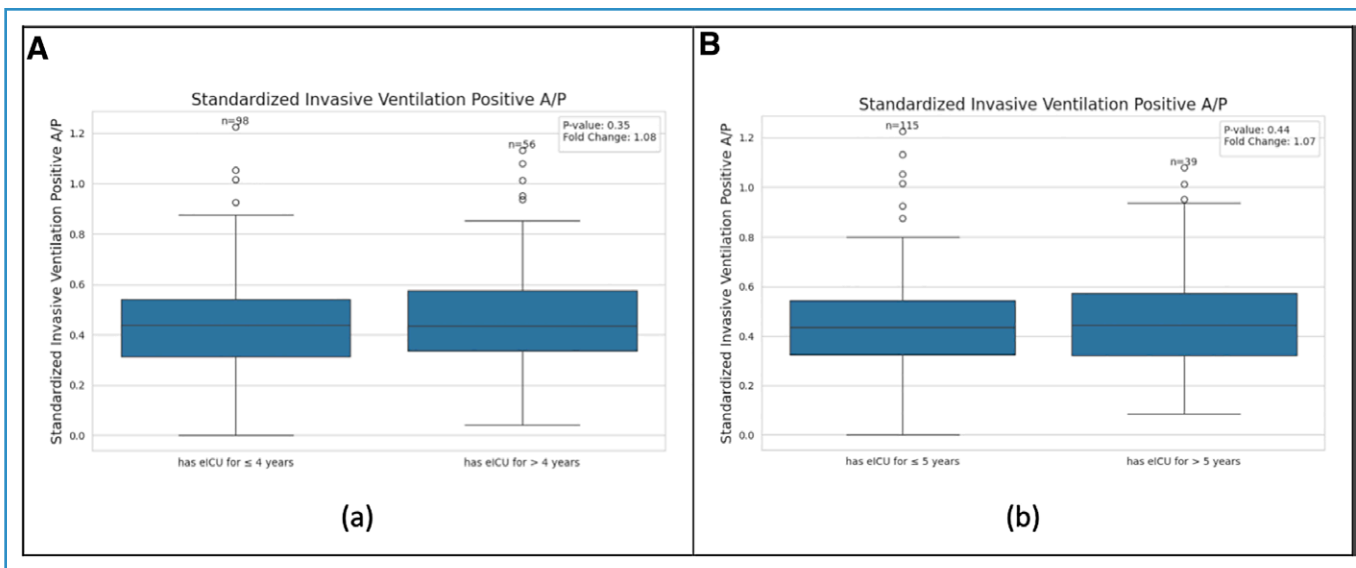


Figure 5. Tele-critical care implementation duration and ICU outcomes: standardized invasive ventilation deployment. Standardized ICU invasive mechanical ventilation rate (ratio of actual values over predicted values [A/P]) (**A** and **B**), in groups of hospitals with tele-critical care implementation durations less than or equal to 4 yr and less than or equal to 5 and greater than 5 yr, respectively (see Supplementary Fig. 3, <https://links.lww.com/CCM/H783>, for a more comprehensive comparative analysis across utilization thresholds ranging from 1 to 7 yr). eICU = electronic ICU.

or less than or equal to 5 years compared with greater than 5 years (**Fig. 5**) or even with threshold years of 6 or 7 years of TCC utilization (**Supplementary Fig. 3**, <https://links.lww.com/CCM/H783>).

DISCUSSION

This study is the first to explore the relationship between the duration of TCC implementation and clinical outcomes in Veterans Health Administration hospitals. An association was observed between extended TCC utilization and a trend toward lower mortality rates, notably in hospitals with TCC affiliation exceeding 5 years. Furthermore, a significant reduction in ICU LOS was noted in connection with prolonged TCC deployment, with this decrease evident within 4 years of implementation. While the standardized rate of invasive ventilation increased during the study period, the actual-to-predicted ratio for the use of invasive ventilation remained unchanged with varying durations of TCC deployment.

The actual mortality rate in the VA hospitals deploying TCC was generally less than the predicted mortality rate (**Fig. 1B**). Although the ICU mortality rate was lower than predicted, the standardized mortality rate showed a downward trend during the study. A significant reduction in the standardized mortality rate occurred

between 4 and 5 years after TCC deployment. Chen et al (5) in a meta-analysis of TCC outcomes did not find a significant correlation between duration of TCC intervention and ICU mortality by meta-regression. Additionally, a lower predicted pre-deployment ICU mortality rate is correlated with minimal to no effect on ICU mortality compared with a higher preexisting mortality rate (7). However, when we compared sites deploying TCC for greater than 5 years to those utilizing TCC for less than 5 years, there was a significant decrease in ICU mortality. Thus, even with a less than predicted mortality rate, TCC was associated with a lower ICU mortality rate after 5 years of deployment.

Within the VA hospitals deploying TCC, the standardized LOS was greater than predicted during the first year of TCC utilization and progressively declined with longer TCC utilization. The effect of the duration of TCC deployment on ICU LOS is less well studied but these results suggest that, with higher-than-expected initial LOS, there was greater opportunity for improvement in the LOS compared with mortality and the impact of TCC on ICU LOS was more prominent.

In contrast to previous studies, we did not find any effect of TCC deployment on standardized invasive ventilation rates; the rate tended to increase over the study period from approximately 0.4 to 0.5. This trend may have been in part due to TCC

assisting facilities with ventilator management and retaining rather than transferring these patients (25). It appears that the reduction in invasive ventilation is likely attributable to broader changes in hospital practices rather than direct influence by the TCC program. It is worth noting that the use of invasive ventilation was less than half of the predicted rate. This could be due to a generally lower acuity rate in the VA facilities covered by tele-critical care, a lower patient count, or the tendency to transfer more complex cases to nearby university or tertiary care hospitals with better staffing and resources. The predictive models used for this work did not use any VA data for training or validation (23, 24). So, even though the training cohorts were large (over 2.6 million patients), there could be differences in acuity and treatments compared with VA patients.

Prior studies suggest that the effect of TCC on various clinical outcomes is dependent upon the outcome levels (or ratios) before TCC deployment (7). TCC implementation reduced ICU mortality when observed-to-predicted ratios were above 1, but showed no significant reduction when ratios were below 1 (7). We found that, even though actual ICU mortality was less than expected, it tended to decline with the duration of TCC utilization and the decline was even more significant after 5 years of TCC deployment. The lower initial ICU mortality may have dampened or delayed the effect of TCC on ICU mortality. These results suggest that the duration of TCC deployment may also affect clinical outcomes. Prior studies suggested that TCC's benefits were dependent upon multiple factors including the technology, operational characteristics of the TCC program, interactions and communication between the TCC and bedside providers, change management strategies during implementation and sustainment, and TCC buy in and acceptance (13–19, 26). With increased duration of TCC implementation, acculturation and acceptance of TCC as an important contributing member of the critical care multidisciplinary team may be critical factors in determining TCC's effectiveness.

Change management science investigators have proposed multiple theories and models outlining the factors and processes that affect the implementation of new practices and suggest “the marathon effect” to explain the waves of change implementation with early adopters, early majority, late majority, and laggards

(27, 28). Adopting and spreading new technologies in healthcare can be challenging. While medical innovations are common, their implementation is often hampered by slow or delayed dissemination. Thus, it can take a long time for new technology to be implemented into clinical practice, with some estimates suggesting it can take up to 17 years (29, 30). Gradual adoption of new technologies may in part explain the longer duration of TCC implementation required to observe changes in clinical outcomes within the VA National TCC Program. Although the VA is a single national healthcare system, there is great heterogeneity across the hospitals and ICUs that constitute the TCC Program. These ICUs range from small (< 10 beds) to large (> 25 beds) combined medical-surgical ICUs to specialized ICUs (medical, surgical, cardiac, surgical subspecialty) units. ICU coverage ranges from 24/7 attending intensivists to a mix of attending doctors and learners (residents and fellows) to ICUs without any attending intensivists. Additionally, hospitals in the VA TCC program vary from small rural, critical access facilities to hospitals that are affiliated with academic medical centers. This diversity illustrates the general applicability of our results but makes it more difficult to identify specific factors that may affect how the duration of TCC deployment influences clinical outcomes.

This study demonstrates that the duration of TCC implementation influences clinical outcomes, suggesting benefits in improving ICU mortality rates and reducing LOS. Nonetheless, several limitations should be considered. The retrospective observational nature of the study limits causal conclusions across larger populations. Differences in technology, staffing, and clinical practices among VA hospitals may have introduced confounding factors. The use of predictive models that did not incorporate VA-specific data might have overlooked unique population aspects. Additionally, external shifts in healthcare policies or practices could have influenced outcomes over time, and the findings may have limited applicability outside the VA system due to demographic and resource disparities. More controlled studies with expanded data inclusion are needed to better understand TCC's long-term effects. Future research should also investigate the mechanisms behind TCC implementation effects on patient care and the change management factors influencing TCC adoption.

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